CLAIMS

1. A piezoelectric single crystal having a complex perovskite structure, wherein the composition of the piezoelectric single crystal contains 35 to 98 mol% lead magnesium niobate [$Pb(Mg_{1/3}Nb_{2/3})O_3$] or lead zinc niobate [$Pb(Zn_{1/3}Nb_{2/3})O_3$], 0.1 to 64.9 mol% lead titanate [$PbTiO_3$], and 0.05 to 30 mol% lead indium niobate [$Pb(In_{1/2}Nb_{1/2})O_3$]; and calcium is substituted for 0.05 to 10 mol% lead in the composition.

2. A piezoelectric single crystal having a complex perovskite structure, wherein the composition of the piezoelectric single crystal contains 35 to 98 mol% lead magnesium niobate [$Pb(Mg_{1/3}Nb_{2/3})O_3$] or lead zinc niobate [$Pb(Zn_{1/3}Nb_{2/3})O_3$], 0.1 to 64.9 mol% lead titanate [$PbTiO_3$], and 0.05 to 30 mol% lead indium niobate [$Pb(In_{1/2}Nb_{1/2})O_3$]; calcium is substituted for 0.05 to 10 mol% lead in the composition; and the composition further contains 5 mol% or less in total of at least one element selected from the group consisting of Mn, Cr, Sb, W, Al, La, Li, and Ta.

3. A piezoelectric single-crystal device having the polarization direction in a [001] direction of an ingot of the piezoelectric single crystal according to claim 1 or 2 and using an electromechanical coupling factor (k_{31}) in a

lateral vibration mode having the end face in a plane perpendicularly cutting a (001) plane containing a [100] direction and a [010] direction being approximately orthogonal to the polarization direction, wherein

when the [100] direction or the [010] direction is defined as 0°, a direction normal to the end face resides within 0° ± 15° or within 45° ± 5°.

4. A piezoelectric single-crystal device having the polarization direction in a [001] direction of an ingot of the piezoelectric single crystal according to claim 1 or 2 and using an electromechanical coupling factor (k_{31}) in a lateral vibration mode having a direction normal to the end face of the single-crystal device in a [100] direction, a [010] direction, or a [110] direction being approximately orthogonal to the polarization direction, wherein

the direction normal to the end face of the single crystal resides in a solid angle of the [100] axis ± 15°, in a solid angle of the [010] axis ± 15°, or in a solid angle of the [110] axis ± 5°.

5. A piezoelectric single-crystal device having the polarization direction in a [001] direction of an ingot of the piezoelectric single crystal according to claim 1 or 2 and using an electromechanical coupling factor (k_{33}) in a

vibration mode in the direction parallel to the polarization direction, i.e., in a longitudinal vibration mode having the end face in a (001) plane, wherein

when the shortest-side length or the diameter of the device end face orthogonal to the polarization direction is defined as a and the device length in the direction parallel to the polarization direction is defined as b, the piezoelectric single-crystal device has the a and the b satisfying the relational formula $b/a \geq 2.5$.

6. A piezoelectric single-crystal device having the polarization direction in a [110] direction of an ingot of the piezoelectric single crystal according to claim 1 or 2 and using an electromechanical coupling factor (k_{33}) in a vibration mode in the direction parallel to the polarization direction, i.e., in a longitudinal vibration mode having the end face in a (110) plane, wherein

when the shortest-side length or the diameter of the device end face orthogonal to the polarization direction is defined as a and the device length in the direction parallel to the polarization direction is defined as b, the piezoelectric single-crystal device has the a and the b satisfying the relational formula $b/a \geq 2.5$.

7. A 1-3 piezoelectric composite formed by arraying a

plurality of the piezoelectric single-crystal devices according to claim 5 or 6 in such a manner that the device end faces orthogonal to the polarization direction reside in one plane.

8. A method for manufacturing the piezoelectric single-crystal device according to any one of claims 3 to 6, the method comprising a polarizing process carried out before or after the cutting of an ingot of the piezoelectric single crystal according to claim 1 or 2 into a single-crystal device material having a predetermined shape in a predetermined direction, wherein the single-crystal ingot or the single-crystal device material is polarized by applying a direct electric field of 350 to 1500 V/mm in the temperature range of 20 to 200°C in a direction to be polarized of the single-crystal ingot or in a direction to be polarized of the cut-out single-crystal device material; or applying a direct electric field of 350 to 1500 V/mm at a temperature higher than the Curie temperature (Tc) of the single-crystal ingot or the single-crystal device material and then cooling to a room temperature while applying the direct electric field.

9. A method for manufacturing a piezoelectric single-crystal device, the method comprises the steps of:

cutting out a single-crystal device material having a predetermined shape in a predetermined direction from an ingot of a piezoelectric single crystal wherein the composition of the piezoelectric single crystal contains 35 to 98 mol% lead magnesium niobate [$Pb(Mg_{1/3}Nb_{2/3})O_3$] or lead zinc niobate [$Pb(Zn_{1/3}Nb_{2/3})O_3$], 0.1 to 64.9 mol% lead titanate [$PbTiO_3$], and 0.05 to 30 mol% lead indium niobate [$Pb(In_{1/2}Nb_{1/2})O_3$]; and calcium is substituted for 0.05 to 10 mol% lead in the composition; and

polarizing the single-crystal device material by applying a direct electric field of 350 to 1500 V/mm along a direction to be polarized of the single-crystal device material in the temperature range of 20 to 200°C or applying a direct electric field of 350 to 1500 V/mm at a temperature higher than the Curie temperature (Tc) of the single-crystal device material and then cooling to a room temperature while applying the direct electric field.

10. A method for manufacturing a piezoelectric single-crystal device, the method comprising the steps of polarizing an ingot of a piezoelectric single-crystal wherein the composition of the piezoelectric single crystal contains 35 to 98 mol% lead magnesium niobate [$Pb(Mg_{1/3}Nb_{2/3})O_3$] or lead zinc niobate [$Pb(Zn_{1/3}Nb_{2/3})O_3$], 0.1 to 64.9 mol% lead titanate [$PbTiO_3$], and 0.05 to 30 mol%

lead indium niobate [$Pb(In_{1/2}Nb_{1/2})O_3$]; and calcium is substituted for 0.05 to 10 mol% lead in the composition by applying a direct electric field of 350 to 1500 V/mm along a direction to be polarized of the piezoelectric single-crystal ingot in the temperature range of 20 to 200°C, or by applying a direct electric field of 350 to 1500 V/mm at a temperature higher than the Curie temperature (Tc) of the single-crystal device material and then cooling to a room temperature while applying the direct electric field; and cutting the piezoelectric single-crystal ingot into the single-crystal device material having a predetermined shape in a predetermined direction.

11. The method for manufacturing a piezoelectric single-crystal device according to claim 9 or 10, wherein the piezoelectric single crystal ingot further contains 5 mol% or less in total of at least one element selected from the group consisting of Mn, Cr, Sb, W, Al, La, Li, and Ta at 5 mol% or less in total.